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Experimental Demonstration of a 400 Gb/s Full Coherent Transmission in an in-field Metro-Access scenario

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ABSTRACT The current challenge for the physical layer of next generation optical access network based on PON architectures is to increase the capacity above 100 Gbps per wavelength. This target may require a revolution for PON, moving from direct detection (DD) to optical advanced modulation formats and coherent detection. In fact, the performances of full-coherent systems for ultra-high bit rates are, in terms of receiver sensitivity, significantly better than standard DD receivers, obtaining power budget of more than 30 dB. In this scenario of large available power budget, it will even be possible to envision a convergence of the access with the metro segment, also considering that wavelength routing functionalities based on Reconfigurable Optical Add Drop Multiplexers (ROADM) can be inserted at the boundary between the two network domains. In this future possible scenario, it becomes thus fundamental to study the resulting power budget for both the metro and the access network, in order to optimize the overall optical performance.

To this end, we show in this paper experimental results obtained on a 33-km deployed metropolitan fiber link on a PM-16QAM full-coherent transmission at 50 Gbaud (400 Gbps) in terms of BER curves as a function of received optical power in a practical emulation of downstream metro+access transmission. A Reconfigurable Optical Add-Drop Multiplexer is introduced in the middle of the link to implement a wavelength routed metro-access scenario.
Keywords: Passive Optical Networks, Metro-Access Convergence, Coherent Transmission Systems, FTTH.

1. INTRODUCTION

In optical access networks, the Passive Optical Network (PON) architecture has become in the last 15 years by far the most commonly used one, with an estimate of more than 100 million Optical Network Units (ONU) sold per year worldwide. The PON-based fiber infrastructure that has been deployed for Fiber-to-the-Home (FTTH) is becoming so widespread that some telco operators are starting to plan in 5-7 years from now a complete decommissioning of the “old” copper-based access networks. Thus, particularly in urban areas, the PON infrastructure can today be considered as the solution that will be used for several decades from now (just like the old copper-based Plain Old Telephone Service, or POTS, has been operational for more than 70 years). As a consequence, the international standardization bodies in this field (namely ITU-T and IEEE) are continuously working on upgrading the physical layer standards for PON: as of today (2023), new installations are transitioning from G-PON (2.5 Gbps downstream, DS) to XG-PON or XGS-PON (10 Gbps), while ITU-T has recently released (2021) the new standard for 50G-PON (for further info, see for instance the introductory Section of [1]). All these standards are still based on binary On-Off Keying (OOK) and direct detection, and the required increase in bit rate was handled by i) introducing stronger Forward Error Correction (FEC) Low-Density Parity-Check (LDPC) codes with BER threshold as high as 10^{-2} ii) assuming high bandwidth Avalanche PhotoDetector (APD) based receivers and iii) introducing (for 50G-PON only) adaptive equalization at the receiver to combat optoelectronic bandwidth limitations.

The discussion in PON standardization bodies is now open for the next generation standard; for instance, in ITU-T workgroups on PON, a one year open discussion on PON evolution has just started, and it will likely lead to a white paper describing the different available technical options. Our best guess is that if the next generation will focus on 100G-PON (i.e. on DS transmission at 100 Gbit/s per wavelength) the solution will still be based on direct-detection (likely coupled with PAM-4 modulation, similarly to what has happened in the datacenter area in the last 5 years) coupled with the use of Semiconductor Optical Amplifiers (SOA), whereas if the next bit rate is 200 Gbit/s per λ, the use of direct detection will become exceedingly critical, mostly due to the very high power budget required in PON (at least 29 dB, but more likely 32 dB) and a transition to advanced modulation formats and coherent detection will be a must [3] [4]. It should be noted that the “commercial” time-frame for 200G-PON is quite far in the future (PON generations typically change every 7-8 years, or even more) so that, potentially, 200G-PON may be commercially deployed in more than 10 years from now. In the meantime, the cost of coherent transceivers, which is today prohibitive for the access ecosystem, may decrease significantly, down to a point that may become of interest also for PON [2]. If and when coherent technology will be adopted in PON, an interesting feature will not only be the possibility to increase the bit rate to 200G (or even 400G) but also to use the advantages in performance of coherent with respect to direct-detection to

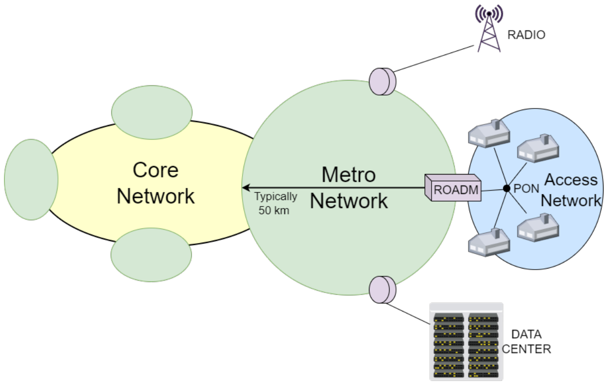

Figure 1: A metro-access converged scenario.

increase the maximum covered distance (which today in PON is limited to 20 km) and/or the achievable power budget. Going one step further, it may be interesting for telco operators to study the option of merging metro and access networking in a single optical domain, as shown in Fig. 1, using Wavelength Selective Switches (WSS) or Reconfigurable Optical Add-Drop Multiplexers (ROADM) at the boundary between the two segments, to enable network reconfigurability at the wavelength level.

In this paper, we experimentally investigate on this wavelength-routed and converged metro-access scenario based on coherent transmission, focusing on the achievable power budget in the metro and in the PON segments. We present a set of experiments that were performed on the setup shown in Fig. 2 (bottom), which is based on a full-coherent PM-16QAM transmission at 400 Gbps over a deployed fiber testbed in the city of Turin, Italy, (Fig. 2, upper part), showing performance that, for the PON access segment, are compliant with the required 29+ dB power budget, together with a large available margin on the metro network.

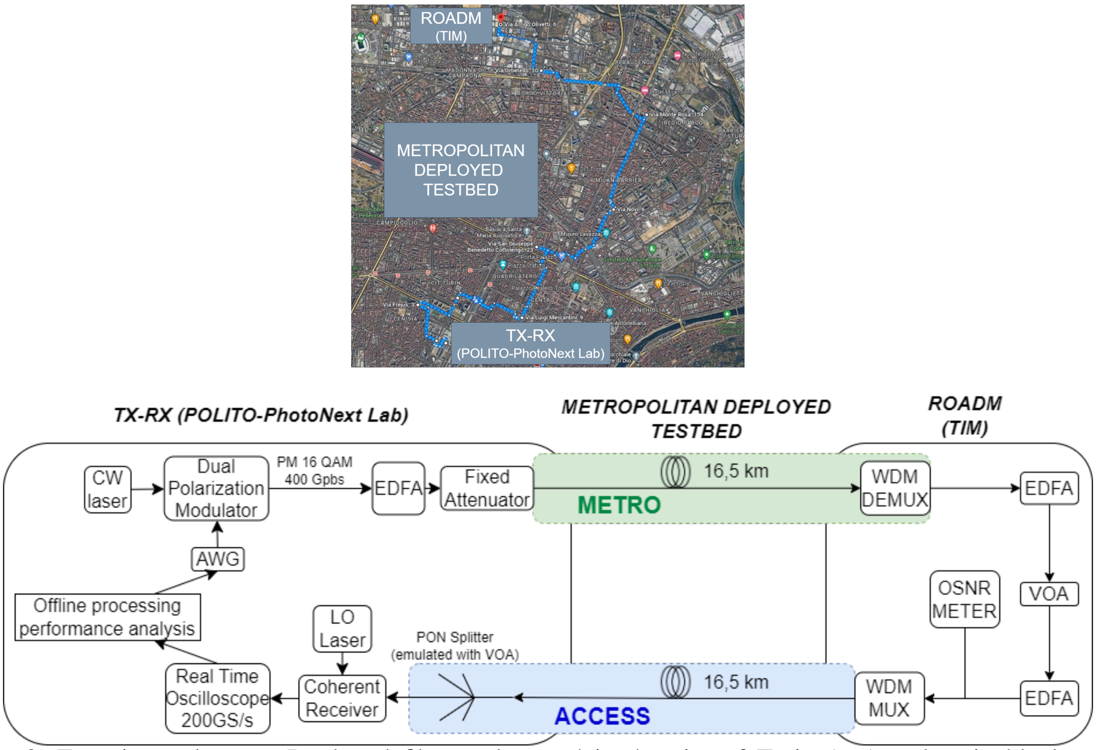

Figure 2: Experimental setup. Deployed fiber path tested in the city of Turin (top) and main blocks of the experimental setup (bottom).

2. Experimental setup and results

We experimentally tested a 50 Gbaud PM-16QAM full-coherent transmission (400 Gbps bit rate) on a 16,5 km + 16,5 km standard single-mode fiber deployed in the city of Turin. The upper part of Fig. 2 shows the actual fibers path on the Turin city Map, while the bottom part of the figure shows our experimental setup. Its main blocks are: 1. signal transmission and detection on the left; 2. the metropolitan testbed in the middle (also represented in the figure above) where we used two fibers connecting two urban laboratories, one placed in POLITO University and one on Telecom Italia TIM premises; 3. the ROADM on the right. The fiber path used as a metro segment is highlighted in green, while the access path is in blue.

The experiment is carried out generating a 50 Gbaud PM-16QAM full-coherent signal, which is transmitted on the "metro path" (16.5 km long SMF deployed fiber with total attenuation of about 11 dB) and reaches the ROADM. The internal structure of the used commercial ROADM consists of five blocks: a bandwidth and wavelength configurable WDM demultiplexer, two optical amplifiers, a variable optical attenuator (VOA) and another bandwidth and wavelength configurable WDM multiplexer. In the first block, the signal is filtered with a bandwidth of 300 GHz and then attenuated to produce different output OSNR values ranging from 25 dB to 36 dB, with approximately 2 dB steps. The second block is an EDFA working in fixed-gain mode. The third block is a VOA with 0 dB attenuation. The second EDFA operates in fixed output power mode (the OSNR is evaluated at the monitoring output of the second EDFA). Lastly, a WDM multiplexer with 300 GHz bandwidth filters the signal again. The signal is then transmitted onto the "access segment" (again 16.5 km of deployed SMF fiber) and it is attenuated at the receiver side by a VOA that emulates the attenuation introduced by a PON passive splitter. The received optical signal is coherently detected, acquired through a real time oscilloscope at 200 GS/s and analyzed by a Digital Signal Processing (DSP) chain to evaluate the BER for each pair of received power level and OSNR.

Fig. 3 shows the resulting BER curves for two different transmitted power levels (9 dBm and 11 dBm) at the input of both fiber segments.

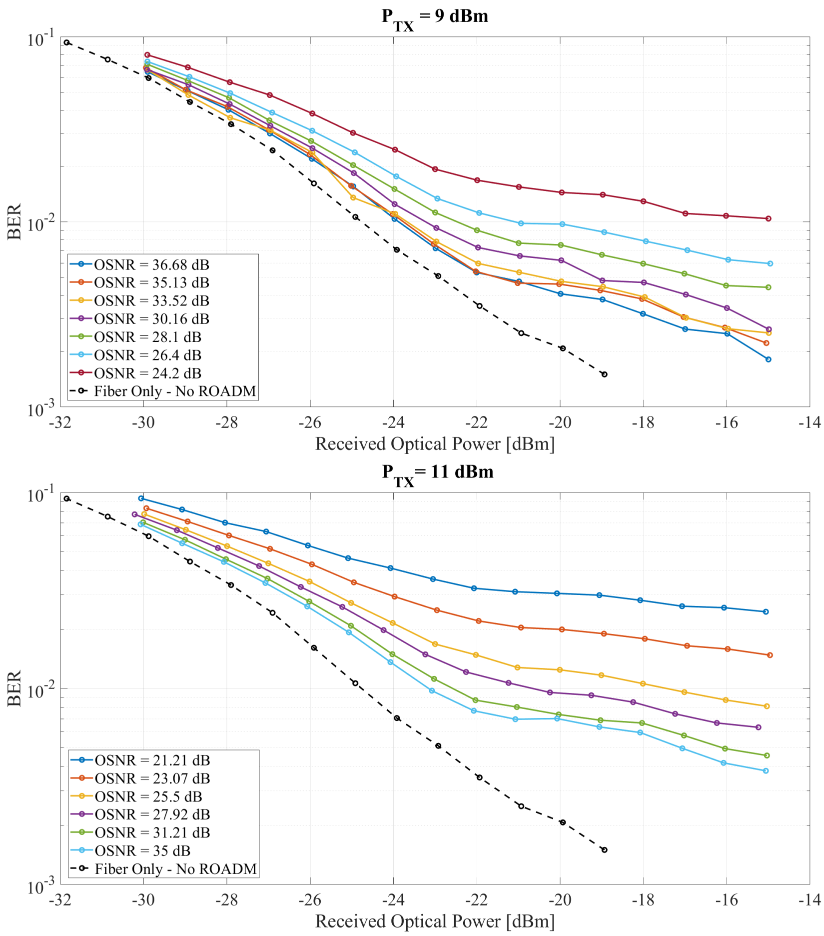

Figure 3: BER curves vs. received optical power (dBm) for different OSNR values and 9 dBm (top) and 11 dBm (bottom) transmitted power. In both cases, the black curve represents the reference limit in absence of the OSNR penalties induced by the ROADM node.

From these two graph in Fig. 3, it would in general be possible to dimension the converged metro-access transmission in terms of power budget introduced in the two segments. To better highlight the resulting performance, Fig. 4 shows the contour plot at BER=10^{-2} (the current BER threshold set by ITU-T for 50G-PON using LDPC FEC codes) versus the two path losses introduced in the metro and in the access segments. Specifically, we define as "Metro Loss" the path loss which is present from the output of the fixed attenuator in the TX-RX block to the output of the WDM demultiplexer in the ROADM, whereas "Access Loss" is the path loss measured from the output of the WDM multiplexer of the ROADM to the input of the coherent receiver. The two curves in Fig. 4 are for 9 dBm and 11 dBm fiber transmitted power.

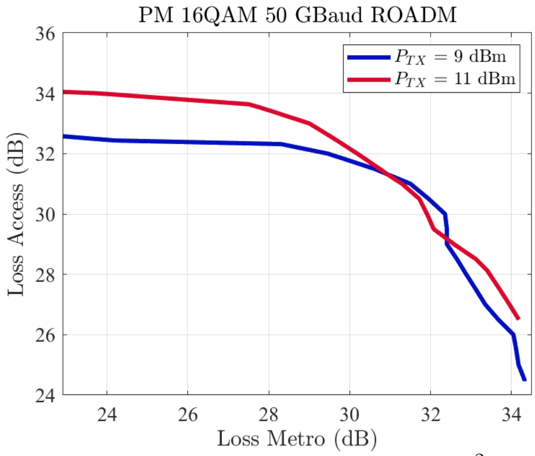

Figure 4: Relation between Metro and Access path losses at $BER = 10^{-2}$. The red line represents a transmitted power of 11 dBm while in blue represents a transmitted power of 9 dBm.

From Fig. 4, which is the main experimental result of our paper, it can be derived that in our specific testbed for 400G-PON:

1) the access segment can for instance reach the 31 dB loss required today by most operators for current PON installations (XG-PON ODN Loss class N1), as long as the loss in the metro segment is not bigger than 31 dB, which actually allows a good margin in dimensioning the metro part.
2) if higher losses are required in the access part, such as the 33 dB ITU-T E1 ODN Loss class target, this is possible by increasing the transmitted power to 11 dBm and reducing the loss in the metro segment to less than 28 dB.

3. Discussion and conclusion

In this work, we experimentally investigated on a converged metro-access scenario using full-coherent 50 Gbaud PM-16QAM transmission (400 Gbps bit rate). It is evident from our work, and in particular from Fig. 4, that a joint design of the two segments should be carried out, due to the fact that the access PON segment is very demanding in terms of link loss. Thus, to achieve the current ITU-T ODN losss targets for PON (set at 29, 31 or 33 dB) it should be ensured that the OSNR level generated through optical amplification in the metro segment is sufficiently high. Besides the physical layer considerations that we started to address in this paper, a converged metro+PON scenario would open many other very interesting aspects at the network layer which are not treated in this paper, such as how to optimally split IP-routing and ROADM wavelength based routing. Another interesting aspect will be related to the potential reduction in power consumption enable by avoiding O/E/O conversion at the boundary of the two segments.

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